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HUMAN STRENGTH CAPABILITIES FOR THE OPERATION OF PARACHUTE RIPCORDS AND RISER RELEASES

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AFAMRL-TR-83-081

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
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Military Specification MIL-P-6645H permits a maximum pull of 27 pounds to activate a parachute ripcord. A test was conducted to evaluate this force. Two hundred eleven physically fit male and female subjects made maximum voluntary ~~exertions on~~ five different parachute ripcord handles with the left hand, the right hand, and with both hands. The applied isomteric forces were recorded. Considerable differences in the recorded forces

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were found to be attributable to to sex and to one versus two hand pulls; lesser differences were caused by variations in ripcord handle types and locations. When both hands were used, almost all male subjects could exceed the permitted 27-pound pull. Significant numbers of female subjects using either one or both hands, and male subjects using only one hand could not exceed 27 pounds of pull. As a result, the authors recommend that the currently specified 27-pound limit not be increased as has been proposed, and that teaching the two-hand pull be continued. The same subjects also performed maximum voluntary exertions on two types of riser releases with the left and right hands. The type of riser release caused a significant difference in the force exerted.

SUMMARY

Military Specification MIL-P-6645H, "Parachutes, Personnel, General Specification for," prescribes a 27 pound force limit to pull a parachute ripcord. Suggestions have been made to raise this force limit, which has the potential of causing problems for female parachutists. Also, each year a number of parachutists are injured because of their inability to realease their parachute risers after having safely descended to land or water. A study was conducted to measure maximum force capabilities of men and women to pull ripcords and to actuate riser releases. One hundred and four men and 107 women served as subjects in tests of their maximum force capabilities in pulling with their right, left, and both hands five different types of ripcord handles on three different models of parachutes. Their maximum force capabilities in actuating two types of riser releases were also measured. Individual forces as high as 205 pounds were recorded; the mean forces over the five ripcord handles ranged from 15 to 83 pounds. On the riser releases, the mean forces ranged between 15 and 32 pounds.

On the average, the forces produced by males were 1.8 times greater than those produced by females on the ripcords; on the riser releases the forces produced by males were 1.5 times greater. Both-hand pulls produced forces that, in most cases, were greater than the sum of single hand forces. When using both hands, male subjects (with rare exceptions) were able to exceed the prescribed 27 pound force limit. A significant number of females, using either one hand or both hands, and male subjects using only one hand could not exceed the 27 pound force limit. Correlations among the forces were found to be moderate, with only a few r values up to 0.85. Correlations between anthropometric measures and forces were low, only rarely exceeding 0.50. This is an indication that body sizes are not very good predictors of a person's ability to apply forces. On the other hand, reasonable indications of the ability of potential parachute users could be obtained by testing them with

a suitably instrumented ripcord handle. It is recommended that the 27 pound limit should not be increased and that the Air Force continue teaching the two-hand pull for deploying a parachute.

PREFACE

The Parachute Ripcord and Riser Release Study was performed under Task 7184, Work Unit 71840831, "Biomechanics for System Design", at the request of the Life Support Systems Program Office (ASD/AES). Work on this study was started in October 1981 and completed in December 1982. The actual experimentation with subjects began on 2 February 1982 and was completed on 23 July 1982.

Dr. Joe W. McDaniel directed this study. Mr. Charles E. Clauser, Dr. Kenneth Kennedy, Lt. Col. Maureen S. Lofberg, and Lt. Col. Edith Kevan performed the anthropometric measurements. Mr. Nilss M. Aume was responsible for the acquisition and installation of the experimental equipment, and the recruiting, scheduling and briefing of subjects. (All of the above are personnel of the Workload and Ergonomics Branch, AFAMRL). Mr. Thomas Garver and Mr. David Casenhiser (University of Dayton Research Institute) performed the strength measurements. Mr. James Crider, ASD Computer Center (ASD/ADSD), was responsible for the initial data treatment and subsequent reduction.

The authors wish to express their gratitude and appreciation to MSgt Kenneth Goldbach, Aircrew Survival Training, (2750 Air Base Wing/OTTS), who willingly shared his professional knowledge of parachutes and their use, and thus contributed significantly to the validity and success of this study.

Thanks also go to Mr. John L. Pearl of the Survival Equipment Shop (4950 Field Maintenance Squadron / MAFFE), whose personnel collected the parachute ripcord pull-force data, and who was helpful on numerous occasions during the instrumentation phase of the experiment.

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INTRODUCTION

Parachutes have been built and used for many years. During this time, a great deal of knowledge has been accumulated as a result of experimentation, testing and useage, and many specifications, standards and practices have evolved for their design, manufacture and use. When the characteristics of the user population change, as it has happened with the introduction of female aircrew members, the scientific basis of the specifications must be re-evaluated.

In this case, the object of concern is Military Specification MIL-P-6645H, dated 27 February 1973, which prescribes that "the force required to operate the manual ripcord system of a packed parachute to cause positive opening of the parachute pack or container shall not exceed 27 pounds". The problem which currently arises is this: parachute manufacturers are suggesting an increase in the force required to operate ripcords, while the Air Force is acquiring growing numbers of female aircrew members whose upper body strength is considerably below that of males. Parachute manufacturers claim that an increase in the allowable activation forces is needed to prevent the retaining pins from slipping out as a result of routine flexing of the pack, causing an inadvertent opening of the canopy, and rendering the parachute unusable until repacked. While this may be a valid concern, its implementation could well result in the manufacture of parachutes which a significant portion of the female or even the male population cannot open. To assess the problem, the Life Support Systems Program Office requested that AFAMRL measure the forces that potential parachute users are capable of exerting on ripcords.

This study also measured the forces that people can apply to parachute riser releases. Riser releases are necessary to detach the canopy after landing to avoid being dragged along the ground or in water under windy conditions. As tension on the risers

increases, progressively greater forces are required to activate the riser releases. If tension increases sufficiently, it may eventually become very difficult if not impossible to release the risers and deflate or collapse the canopy.

Twelve body dimensions were measured on each subject, both to ascertain that the subject population approximated the Air Force flying population and to identify correlations of body size with magnitude of the applied forces.

According to parachute riggers at the Wright-Patterson Air Force Base Parachute Shop, part of the 90 day periodic repacking procedure involves pulling the ripcord and measuring the force required to activate the ripcord. The method of checking the force is as follows: the parachute is placed on the packing table with the canopy pack down and the parachute rigger attaches a force-indicating scale to the ripcord handle. The end of the ripcord housing next to the handle is held in one hand, and the scale is held in the other hand. Then the rigger slowly increases the force until the handle is extracted from the retaining clip. The maximum force on the scale is observed and recorded. According to the riggers, the force that is needed to pull the ripcord handle out of the retaining clip is often greater than the force required to pull the pins and deploy the canopy.

Several authors have previously studied human ability to apply forces to ripcord handles. Martin (1945) is one of the earliest known works. More recently, there have been tests by Reid (1973), Bullock (1978), and Pheeny (1982). AFAMRL also obtained ripcord pull force data which had been collected during the Sport Parachutist Nationals in 1979. These studies are described in the Discussion section of this report and, where relevant, the results compared to data obtained in this study.

METHOD

Apparatus. The apparatus used in this study consisted of five ripcord configurations mounted on three parachutes (one chestpack and two backpack types) and two riser releases.

Figure 1. Chestpack Parachute, with Side Pull.

The chestpack parachute shown in Figures 1 and 2 consisted of a harness (PCU-17/P), which a crewmember wears while in flight, and a separate canopy pack (C-12) which the crewmember attaches to

the front of the harness just before bailing out. The standard ripcord handle is mounted in front of the pack on the right side, and the pull is horizontally to the right using the right hand as shown in Figure 1. Also used with the chestpack (Figure 2) was an experimental upward-pull ripcord mounted in the front with the handle at the top of the pack. A quick-change attachment permitted using the same handle and force transducer for both types of pull.

Figure 2. Chestpack Parachute, with Upward Pull.

The first backpack parachute, shown in Figure 3, consisted of a harness (Torso Harness Asembly PCU-15/P) which would be worn by the crewmember and a separate canopy pack (A/P 28S-20 Parachute Assembly Pack), attached to the harness by the two riser

Figure 3. Backpack (Floating) Parachute with "L" Handle, Left Hand Pull.

releases. For the sake of brevity, this parachute will be referred to as "the floating pack parachute" in the rest of this report. The left riser contained the ripcord housing. Opening the riser releases would completely separate the two parts. Because of this design, the canopy pack could move about rather freely and, to avoid excessive motion of the canopy pack during

pulls on the ripcord, a separate strap was installed at the bottom of the pack and fastened around the subject's thighs, slightly above the knees. The ripcord handle (called the "L" handle) was approximately even with the leftmost edge of the subject's ribcage and, during a pull, between 6 and 8 inches below the top of the shoulder.

Figure 4. Backpack Parachute (BA-18) with Blast Handle, Both Hand Pull.

The second backpack parachute had a similar type of harness, but the canopy pack was an integral part of it, inseparably attached

at the top and bottom of the harness. The ripcord guide was attached along the left riser. The ripcord handle was positioned approximately even with the left edge of the rib cage, and between 10 and 12 inches below the top of the shoulder. Two different, quickly interchangeable, handles were used with this parachute. When used with the blast handle as in Figure 4, the parachute was equivalent to a BA-18 parachute. When used with the "T" handle as in Figure 5, it was equivalent to a BA-22

Figure 5. Backpack Parachute (BA-22) with "T" Handle, Right Hand Pull.

parachute. The handles, with some of their more important dimensions, are shown in Figure 8.

All three parachutes were suspended from negator springs which supported their weight. This was an attempt to approximate a free-fall condition. The normal operational configuration of the parachutes was modified by replacing the retaining pins (which keep the cover flaps in place and are pulled out to deploy the canopy) with cotter keys to keep the parachutes from opening. The ripcord cables were attached to electronic force transducers, which were suitably anchored to the parachute bodies. Thus, when a subject pulled on a ripcord, there was only minimal motion in

Figure 6. Riser Release Framework, with Koch Type Release.

the ripcord (caused by some give on the subject's shoulder and in the canopy pack where the ripcord was attached) but the force of pulling was sensed and, after appropriate amplification, was recorded on magnetic tape for subsequent processing on a

computer. The force was also recorded on a paper strip recorder as a check on the apparatus and on the procedure.

The two riser releases were the Koch type and the Frost type. Their essential features are shown in Figure 9. To activate the Koch type release (Figure 6), the user raises a spring-loaded safety cover, and then, with fingertips, pulls down the release in a rotational motion. On the Frost type shown in Figure 7, the

Figure 7. Frost Type Release, Left Hand Activation.

user raises a safety lever on the bottom of the release (usually with the thumb) and pulls down the release lever on top of the release with the fingertips. The safety lever on the Frost type provides a support enabling the operator to squeeze the two

levers together. There is no such support on the Koch type release, so that squeezing is not possible.

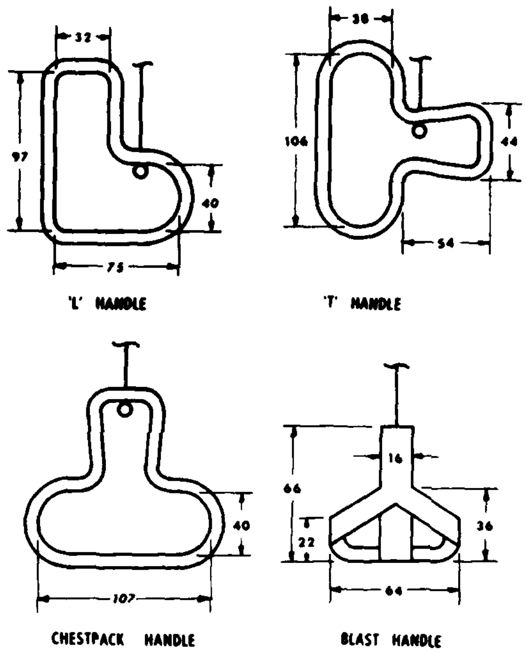

Figure 8. Parachute Ripcord Handles, with Dimensions in Millimeters.

Each riser release was mounted on a framework which simulated the position and angle of a taut riser which occurs when a user is dragged along the ground or in water. The riser releases were approximately even with the top of the subject's shoulder, and positioned even with the leftmost edge of the rib cage. The left shoulder was placed under a strap, which was attached to the framework and simulated part of the parachute harness thus helping to keep the subject's body in the required position. The framework could be adjusted up and down so that there was a slight but definite pressure on the subject's shoulder when

standing erect in the experimental position.

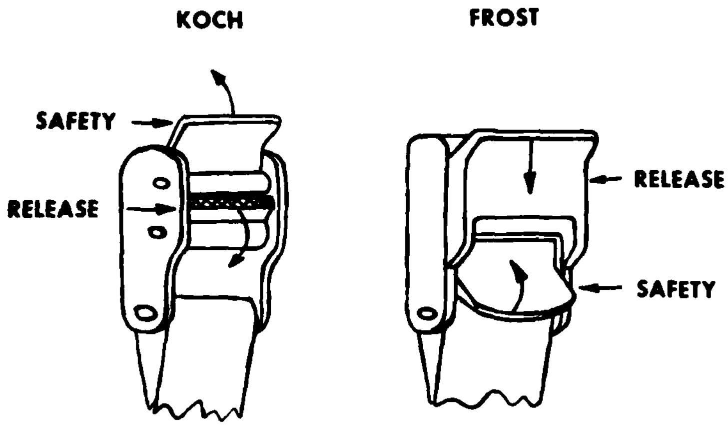

Figure 9. The Koch and the Frost Types of Riser Releases.

Subjects. One hundred four male and 107 female subjects took part in this study. Volunteer military and civil service personnel from Wright-Patterson Air Force Base as well as paid volunteers from local universities were used. With only a few exceptions, the subjects were not actual aircrew members. In an attempt to approximate an aircrew population, most subjects selected were between 18 and 40 years old, and were taller than 64 inches. In the recruiting announcements for subjects, however, no mention was made of height/weight criteria which govern the selection of USAF flying personnel. As a consequence, some of the subjects were outside the allowed weight limits; some of the female subjects were under the stature limit of 64 inches. The performance of these subjects not meeting the body size requirements did not differ from the other subjects, so their data were included.

To avoid causing or aggravating any physical or medical problems, only subjects without any known upper body disabilities were accepted. All subjects read the general instructions (Appendix 1), after which informed consent forms were executed.

Subjects wore indoor clothing (no coats or jackets) of their own choice, except that females were asked to wear pants or slacks to accommodate the parachute leg straps. During the experimentation subjects also wore summer-weight Nomex flying gloves.

Ripcord Test Procedure. Subjects assumed a slightly bent stance during the actual exertions on the ripcords, approximating the posture of persons wearing tightly adjusted harnesses during an actual jump.

On the chestpack, the ripcord handle was always grasped with the four fingers inserted through the loop of the handle and with the palm of the hand toward the subject's body. Only single hand pulls were possible on this parachute. For the side pull, the direction was horizontally to the right. According to the published operating procedures, the left arm is placed under the pack, with the hand grasping the pack and pressing it against the body, thus providing some support and preventing the pack from moving away when the handle is pulled. With the experimental upward pull (Figure 2), either hand was used to pull; the unused hand was placed on top of the pack to counteract the forces of the pull and to keep the pack from being pulled up. The subject was directed to pull upward and slightly away from the body. There seemed to be a natural tendency to pull inward which is impractical in an operational situation since pulling the ripcord even slightly inward results in the parachutist hitting him or herself in the face.

On the floating pack parachute, which was equipped with the "L" handle (Figure 3), the four fingers were inserted through the loop, with the palm of the hand toward the subject's body. This

was done alternately with the left, right, and both hands. The direction of pull was forward in a sagittal plane and approximately 60 degrees below horizontal.

On the BA-18 backpack parachute, when using the blast handle, the fingers were always wrapped around the handle since the existing loops are too small to accommodate the fingers. On two-handed pulls, the right hand was placed on the handle first, and the left hand placed on top of the right hand. When using the "T" handle (the BA-22 configuration) with right-hand pulls, the four fingers were inserted through the loop. With left-hand pulls, the thumb rather than the fingers was inserted through the loop. On both-hand pulls, the left-hand fingers were wrapped around on the outside of the horizontal part of the handle, and the right hand placed through the loop. The direction of pull was forward in a sagittal plane and approximately 60 degrees below horizontal.

On both backpack parachutes, when single-hand pulls were executed, the unused hand was held away from the body as shown in Figures 3 and 5.

In the ripcord tests, the subject was instructed to await the order "ready... and pull" and then, suddenly, jerk on the ripcord with maximum force and then hold the maximum for 5 seconds. This resulted in a fairly good jerk on the ripcords, accompanied by a force spike, after which the force settled down to some fairly even level. Upon observing the start of an exertion, the experimenter started a timer which produced an auditory signal after five seconds upon which the subject released the ripcord or the riser release. This is the standard procedure for testing static human strength as recommended by Kroemer (1970) and Caldwell (1974).

To minimize the effect of fatigue, subjects were given a two minute rest period between exertions which required use of the

same muscles. For the same reason, the order of testing on the parachutes was counterbalanced across subjects. As changing parachutes was fairly time-consuming, the three possible hand applications (left, right, and both) were randomly ordered within each parachute test before changing to the next parachute.

Programming for the data reduction instructed the computer to look for a force exceeding a preset minimum value, which signalled the start of an exertion. Anything recorded after the fourth second was disregarded by the computer, even though the subject continued to apply the force for another second. Three performance measures were derived from the recordings: first, the jerk force, defined as the maximum instantaneous force during the first second of the exertion (and its time of occurrence); second, the maximum force (peak) occurring during the first four seconds of the exertion (and its time of occurrence); third, the sustained isometric force, for which the first second of the exertion was disregarded, allowing the force to settle down to an even value. The recorded force was then averaged over seconds 2, 3, and 4, and this value was used in the subsequent analyses as the sustained isometric force.

Riser Release Test Procedure. The procedure was similar for the riser release tests. Subjects were presented the two types of riser releases in a counterbalanced order. Also, half of the subjects had the left hand tested first; half, the right. The both-hand condition is not appropriate for the riser release operation. The riser release was always positioned at the subject's left shoulder.

Subjects were instructed to apply their maximum force, then hold it for the five second test period. A "jerk" was not requested. The sustained isometric force is the maximum voluntary force averaged over seconds 2, 3, and 4 of the five second exertion.

RESULTS

<u>Maximum Forces.</u> As previously pointed out, an initial force spike, caused by the sudden application of the force or impact loading, was expected for the ripcord exertions. One of the data items recorded during the data reduction was the time of occurrence of the maximum force over the entire exertion. The initial expectation was to find the maximum forces during the first second. This expectation did not materialize. The times when the maximum forces occurred were sorted, and are shown in Table 1.

It is obvious from this table that the initial jerk or impact loading did not occur, at least not as frequently as expected. In addition to the fact that a laboratory test is, of course, not a life-or-death situation and subjects did not have any incentive to overexert themselves, two further possible explanations for the absence of initial force spikes were identified. The first is the fact that the ripcord, in its housing, goes over the fleshy part of the subject's shoulder. This is not a solid support but can give when a force is applied to the handle causing the impact force to be attenuated considerably, so that the initial force spike did not show up, at least not at the retaining pin end of the ripcord, which, of course, is the location of major interest.

A chronological listing of the times of maximum force was reviewed, and 50 subjects out of the 211 showed jerk forces for the early exertions but not for the later ones. This suggests the second explanation: it is possible that the subjects tried a few hard jerks and discovered that they caused pain so, on later pulls, they approached the handles more cautiously, building the force up gradually. For most subjects, however, there was no initial jerk force, even on the early trials, so the theory of attenuation by the shoulder is more likely to be the reason. As a consequence, "Maximum force during the first second" was judged to be of little if any value and was not used or considered any

further.

The ratio of maximum force (selected from the entire 4 second exertion) to sustained isometric force was computed for a sample of exertions. The ratios were found to range from 1.02 to 1.20, with a majority between 1.04 and 1.07. This is an indication that the recorded maximum force is a more or less slight random perturbation in the applied force level, and, being so close to the sustained force, is of no engineering significance.

The sustained isometric force (the average force over seconds 2, 3, and 4 of the exertion) appears to be the only one that parachute users can be counted on to produce consistently and reliably, and therefore it is the only force that should be used for making engineering design decisions. In the remainder of this report, it will be the only one considered.

<u>Isometric Forces on Ripcords.</u> Results of the sustained isometric forces exerted by the subjects on the ripcords were tabulated and are presented as summary statistics in Table 2. The means for males and females, as well as the range of forces (male maximum and the female minimum forces), were plotted and are presented in Figure 10.

Analyses of variance were performed on the data. The ripcord isometric strength data and the riser release data were analyzed separately. For the ripcord data, only those variables and interactions that were significant at $P < 0.001$ are given in Table 4, and the results are plotted in Figures 11 and 12.

It can be seen in Figure 10 and in Tables 2 and 4 that the three main effects (sex, handle, and hand) were significant. As could be expected, there was a large and significant difference between male and female strength capabilities, the males on the average being almost twice as strong as the females. The ratios of the mean forces (males to females, averaged within an experimental

condition) ranged from 1.66 to 1.90, with a mean ratio of 1.80. The both-hand pulls resulted in almost twice the force produced by single-hand performance. In fact, with the exception of females on the "L" handle, the sum of the individual hand forces was less than the force produced when using both hands (see Table 5). It is possible that when using both hands, the muscle tensions in the body are more symmetrical or balanced than they would be when using one hand, and that this results in a slightly higher combined force.

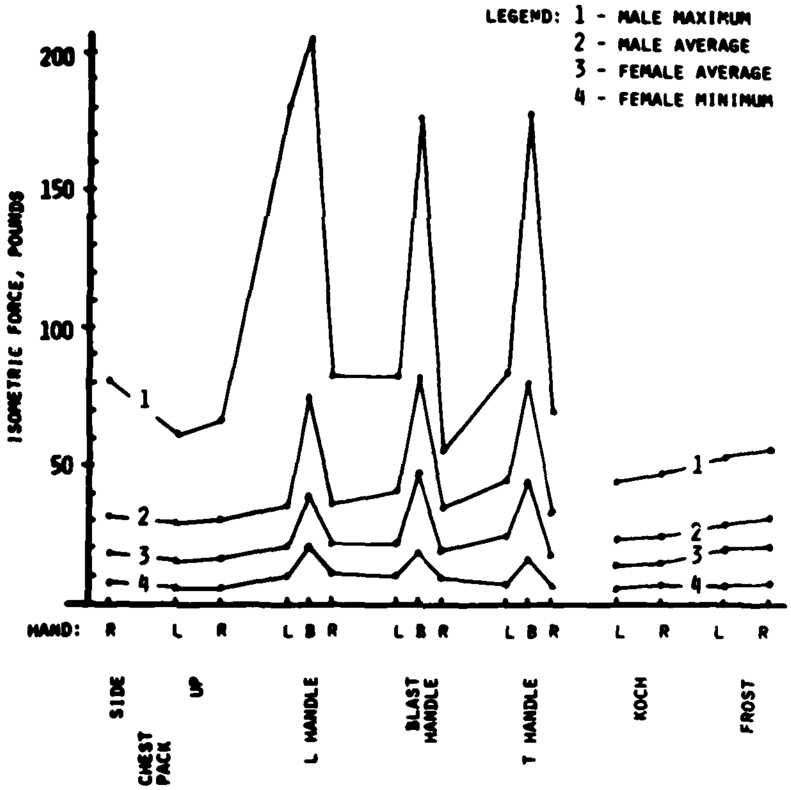

Figure 10. Means, Maxima, and Minima of Isometric Forces over the Experimental Conditions.

The handles main effect as well as the handle-by-hand interactions were significant (see Figure 11). Of the handles, the upward pull on the chestpack produced the lowest forces, followed by rather closely spaced forces on the "L", blast, and "T" handles. A supplementary analysis (the Newman-Keuls Test) was performed, and its results showed that the upward pull was significantly different from the remaining three, which were not significant among themselves. With regard to the handle-by-hand

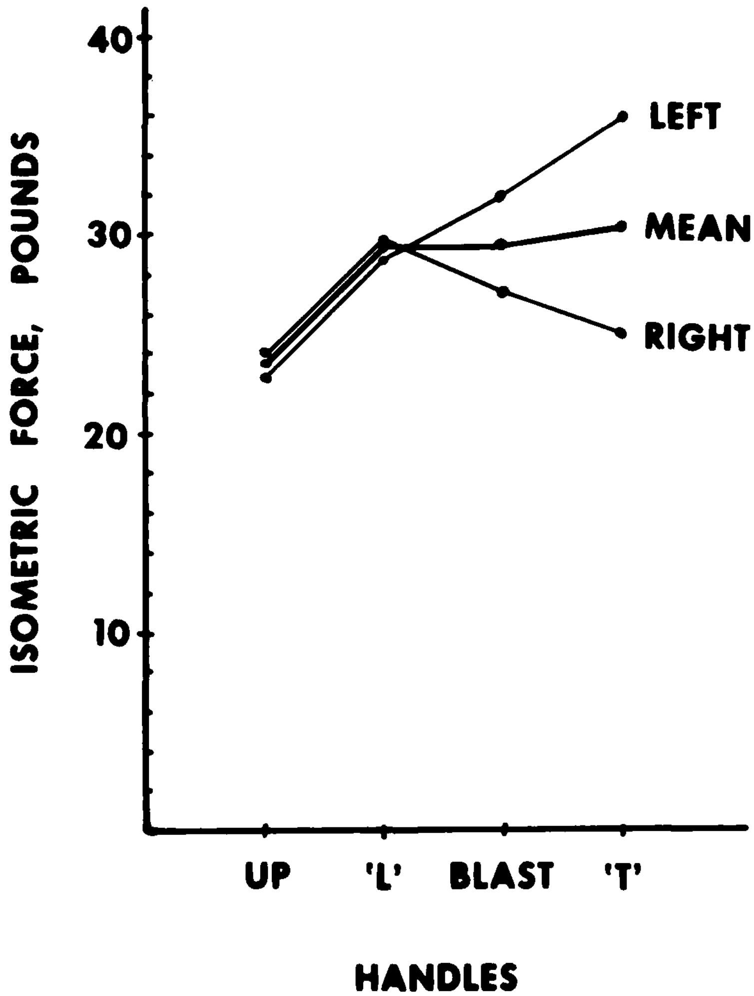

Figure 11. Isometric Forces on Parachute Ripcords: Handle Main Effect, with Handle x Hand Interaction.

interaction, the left and right hands produced no force difference on the upward pull and on the "L" handle, but the left hand was considerably stronger on the blast handle and stronger still on the "T" handle. In the latter two conditions the ripcord goes over the subject's left shoulder, thus providing a reasonably solid support against which the left arm can pull. The chest pack and the floating back-pack, being loose, did not

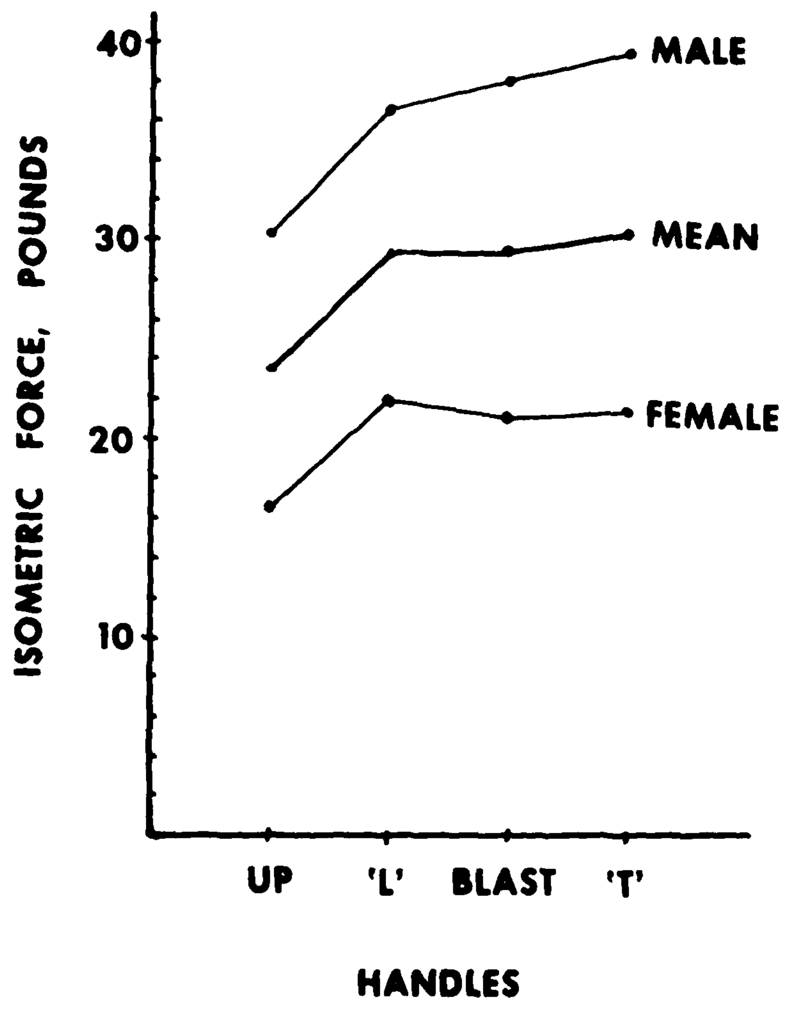

Figure 12. Isometric Forces on Parachute Ripcords: Handle Main Effect, with Handle x Sex Interaction.

provide this support, and, of course, the support was not there for the right arm. A further consideration is the angle of the elbow joint. The left arm may have had a more favorable mechanical advantage. In other words, the right hand would have produced larger forces if the ripcord had been on the right side of the body.

A significant handle-by-sex interaction was also found. The data plotted in Figure 12 reveal that the males produced a larger force on the blast and the "T" handles relative to the "L" handle, while the females had slightly lower forces on the blast and the "T" handles relative to the "L" handle and the upward pull. There is no clear indication of what caused this difference in performance, although the angle at the elbow may be involved here, as the male's arm length is approximately 5 cm longer.

The pattern of forces as produced by the two sexes over the experimental conditions, as can be seen in Figure 1, was remarkably similar.

Isometric Forces on Riser Releases. The last analysis of variance was performed on the riser release data. The results of this analysis of variance are presented in Table 6, again listing only the effects that were significant at $P < 0.001$. Only the three main effects were found to be significant. From Table 3 and Figure 10 it is obvious that males are stronger than females. The ratio of forces, male vs. female, averaged to 1.50 (as opposed to 1.80 on the ripcords), so here the males were not at such a strength advantage. The right hand produced a higher force than the left hand, although only by a few pounds. This may be caused by a higher grip strength in the right hand (similar in magnitude to the difference in the riser release forces), or by the fact that during the test, the riser releases were always on the subject's left side, so that when the right hand was used, it was in a cross-over configuration. The

cross-over method, which places the arm in a more comfortable position, reportedly is the method taught to, and used by, aircrew members.

Among the riser releases, the Frost design produced the highest forces. The fact that the safety catch can be used as a support against which the hand can develop a squeezing force may have contributed to this force difference. The Frost design is also easier to operate, as both the safety catch and the release itself are exposed, while in the Koch design the spring-loaded safety cover has to be lifted up so that the release can be reached, a rather difficult task when wearing gloves. Test results suggest that the Frost design seems to be the more desirable of the two.

Distribution Analysis. The major goal of this study was to determine the proportion of persons who can meet or exceed the 27-pound force limit on the ripcord, keeping in mind that strength standards for safety and life support items are based on first percentile capabilities. Toward this end, the cumulative frequency distributions were plotted and are presented in Figures 13 through 22. From the plots and the computer analyses the percent of the subject population that could not exceed the 27 lb. limit was determined. These results are presented in Table 7.

On the chestpack only a few females and slightly over one half of the males exceeded the 27-pound limit (see Figures 13 and 14). However, judging from the design of the pack (the ripcord is very short and straight), the actual forces required may be significantly lower than 27 lbs. A review of the Parachute Technical Order disclosed that the chest packs do not have any specified force limits, but the size of the retaining pocket is specified and checked, which then determines the amount of friction and thus the force needed to extract the handle. The observed forces were recorded on 45 parachutes of the BA-18 type

(blast handle equipped). A summary of these results is given in Table 8. The forces range between 16 lbs. and 24 lbs., with an average of 19.26 lbs. According to the Parachute T.O., this particular parachute has a specification of 20 $\pm$ 5 lbs.

Only single-hand pulls are possible on the chestpack, and they are not in the locations and directions of maximum human force capability. The experimental upward pulls produced slightly lower forces than did the side pull. This observation, together with the possibility of a parachutist being hit in the face during ripcord extraction, diminishes the desirability of designing chestpacks with upward pulls. On the other hand, these disadvantges may be outweighed by the fact that the ripcord on the chestpack can be activated by either hand.

Data for the backpacks (Figures 15 through 20 and Table 7), reveal that practically all males exceeded the limit when using both hands. Approximately 10 percent of the females were below the limit when using both hands. While it is possible that, due to such factors as selection and training, aircrew members could be stronger than the weakest of the subjects who participated in this study, the percentages in the single hand pulls indicate that a good share of both females and males would have difficulties when using only one hand.

Although the riser releases do not have any prescribed force limits, plots of the distributions of forces are presented in Figures 21 and 22. Admittedly, it may be difficult to establish a norm or standard for riser releases, as the force required to activate them is proportional (it may or may not be linear) to the tension applied by the risers. The data are presented here for use by parachute designers or investigators seeking to establish performance characteristics of riser releases.

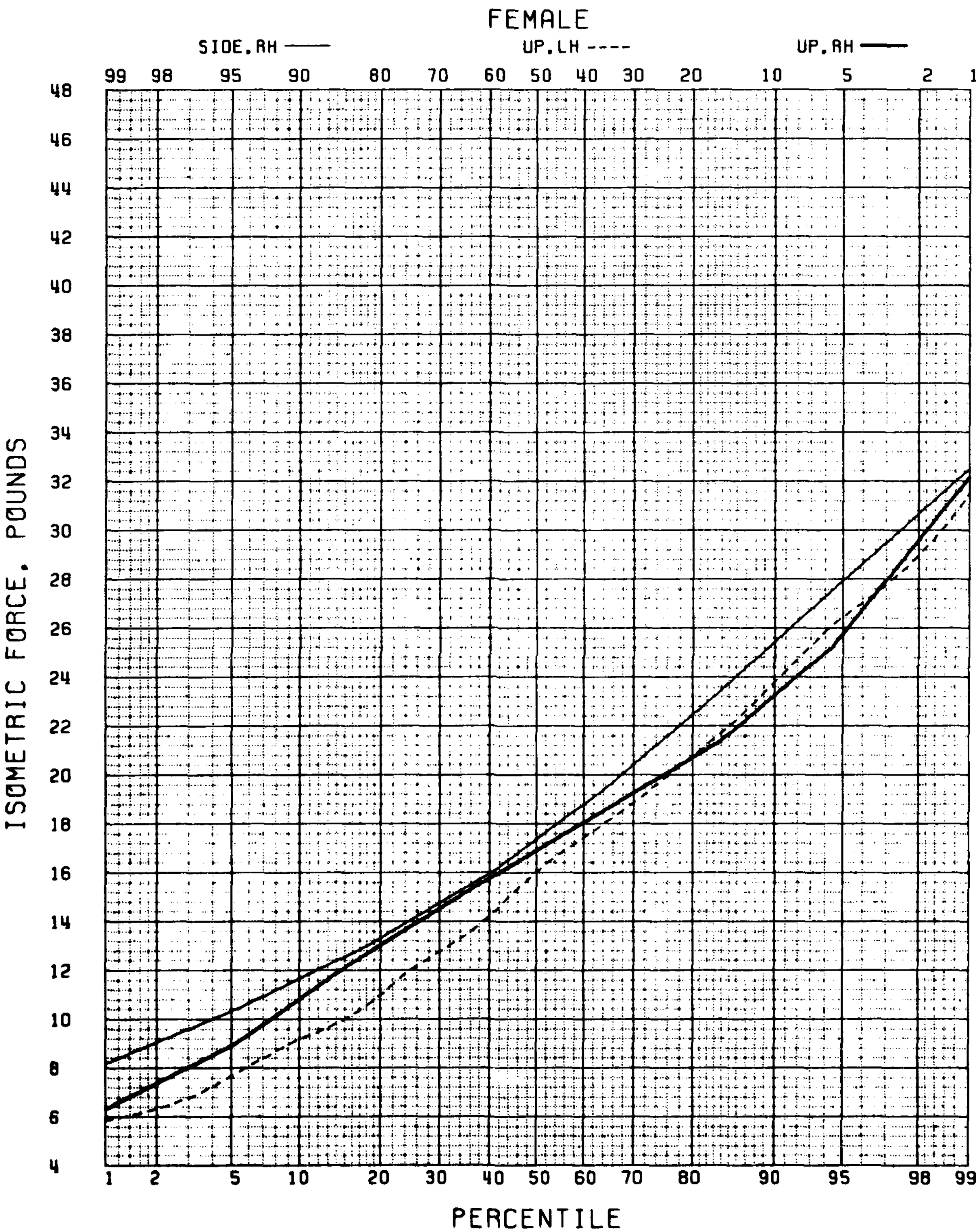

Figure 13. Distribution of Female Isometric Forces on Side and Up Pulls, Chestpack Parachute.

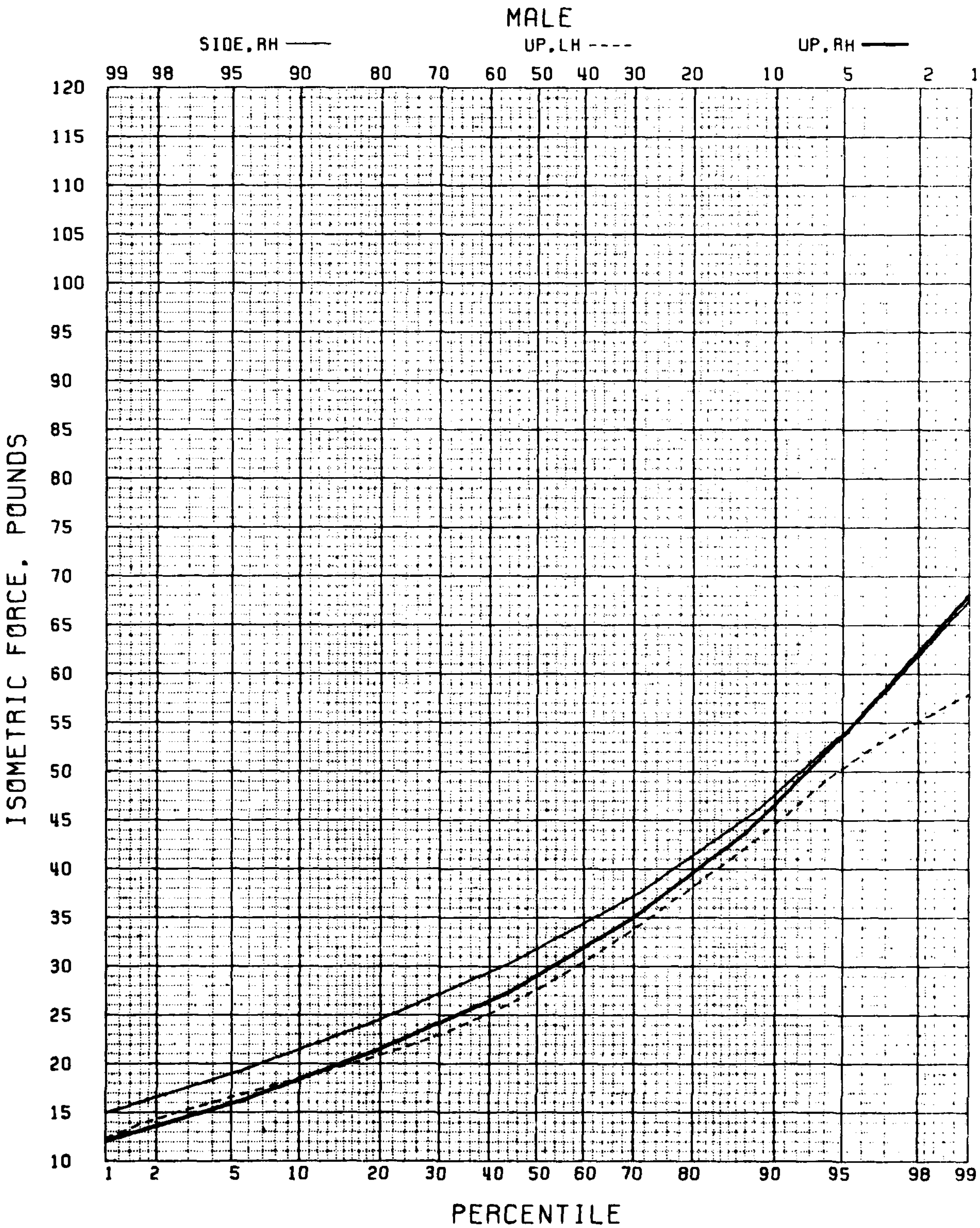

Figure 14. Distribution of Male Isometric Forces on Side and Up Pulls, Chestpack Parachute.

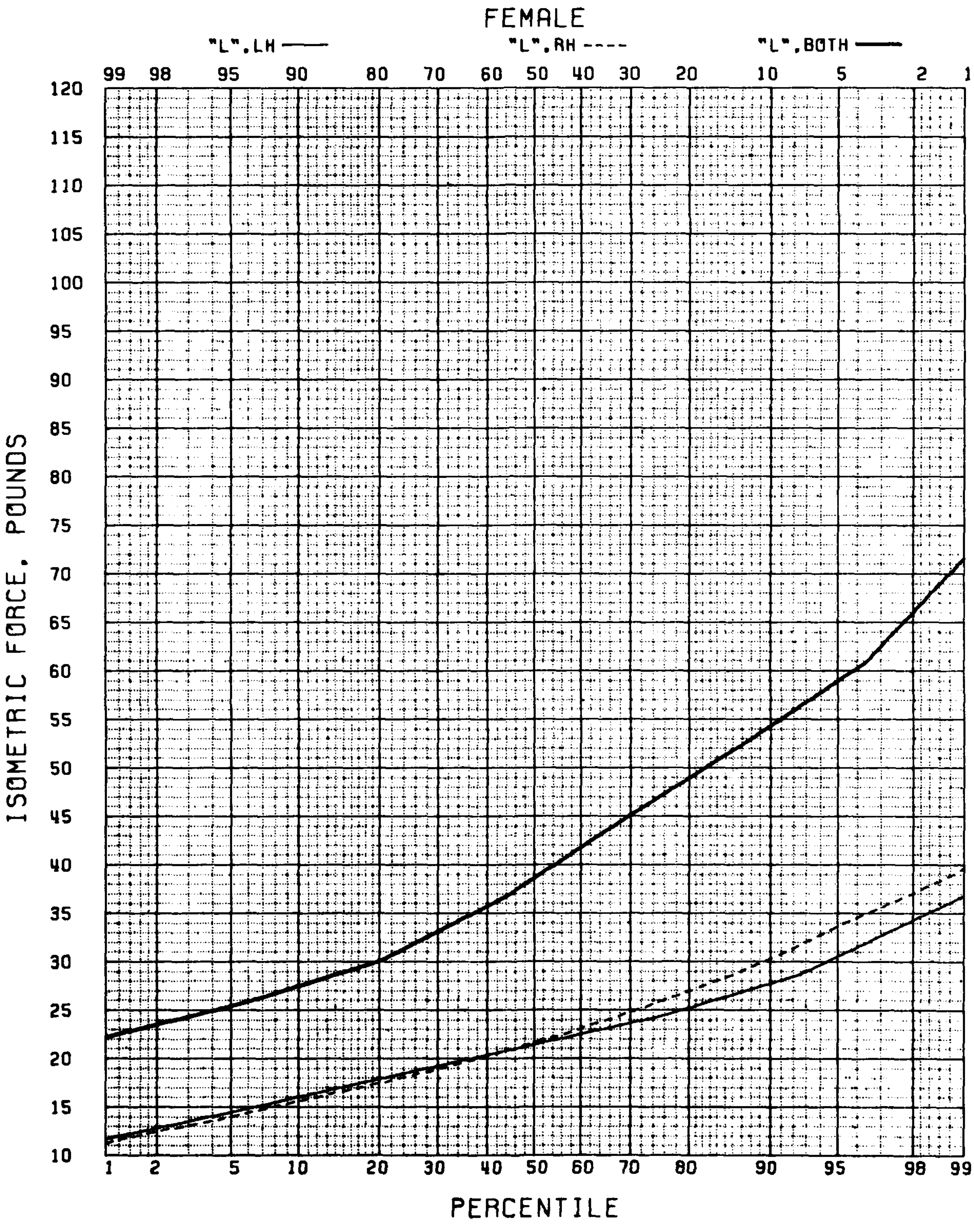

Figure 15. Distribution of Female Isometric Forces on "L" Handle, Floating Pack Parachute.

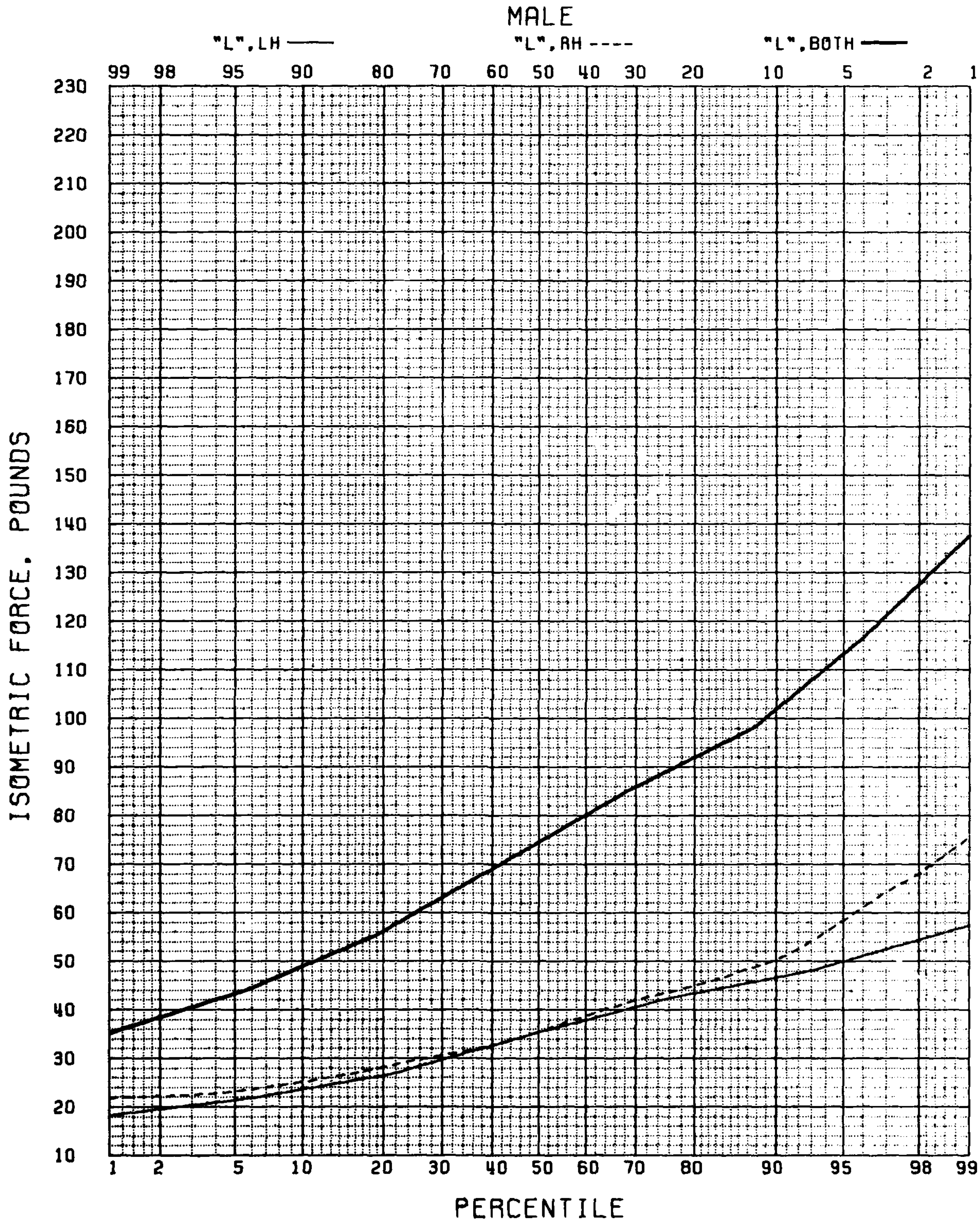

Figure 16. Distribution of Male Isometric Forces on "L" Handle, Float'ng Pack Parachute.

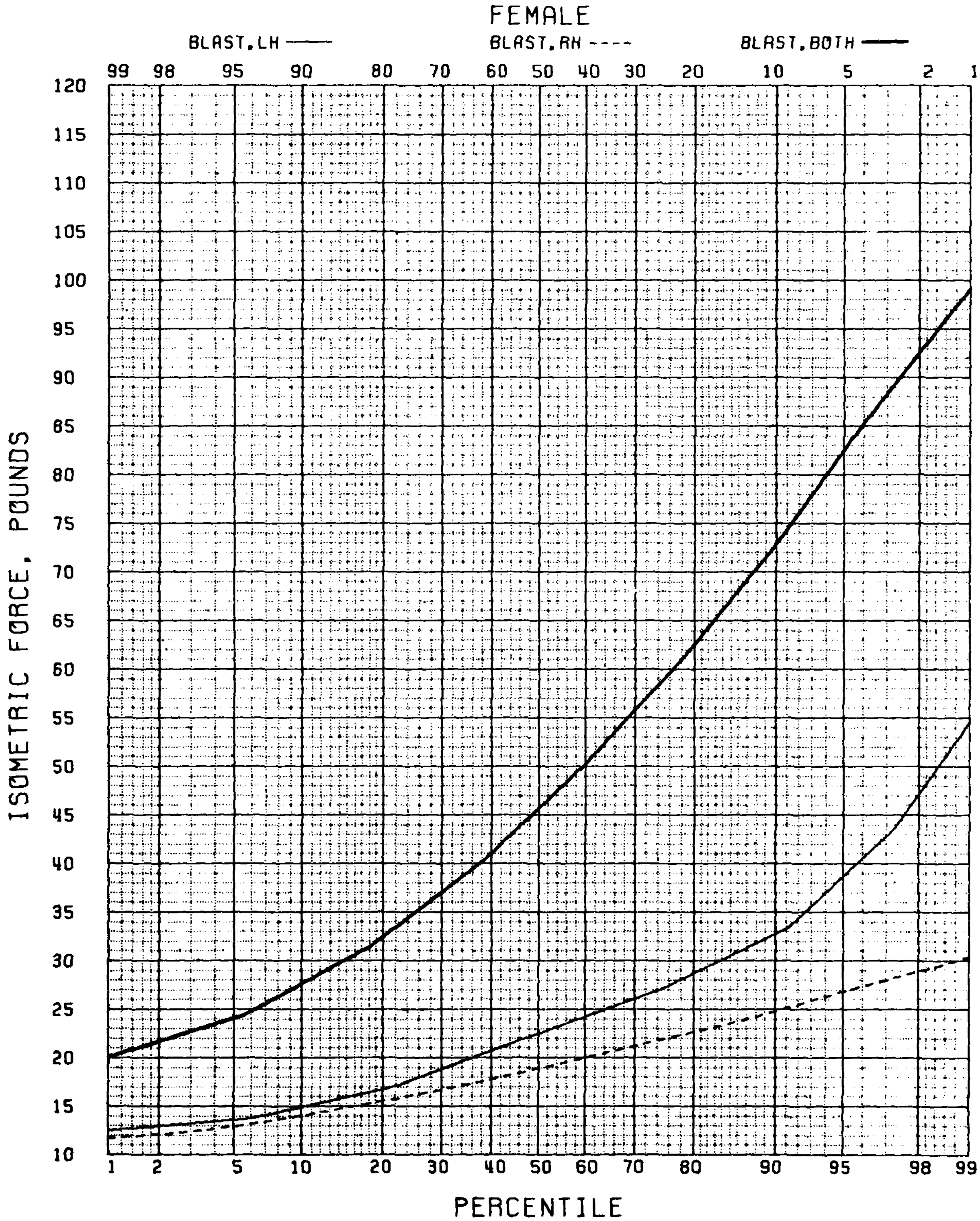

Figure 17. Distribution of Female Isometric Forces on Blast Handle, BA-18 Parachute.

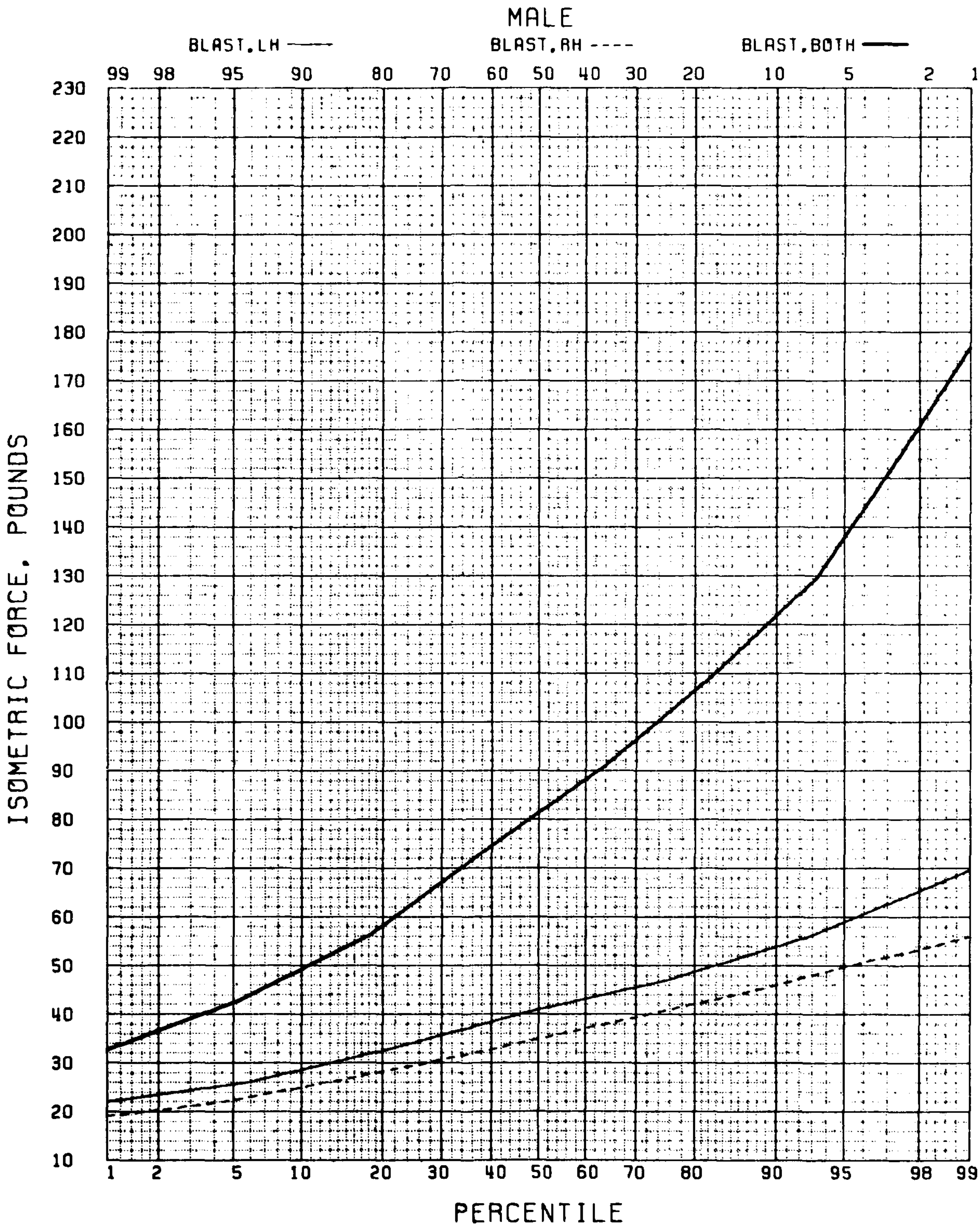

Figure 18. Distribution of Male Isometric Forces on Blast Handle, BA-18 Parachute.

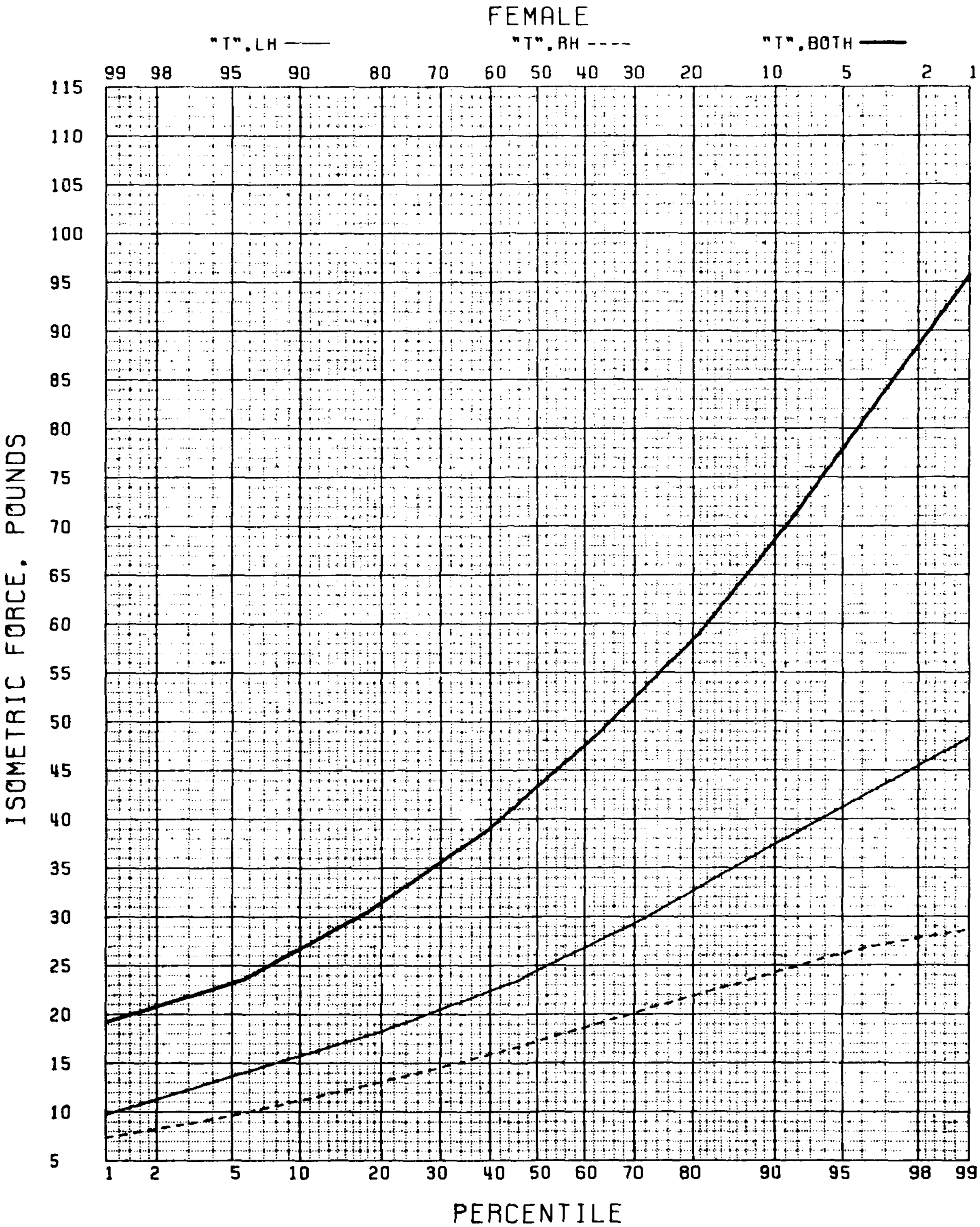

Figure 19. Distribution of Female Isometric Forces on "T" Handle, BA-22 Parachute.

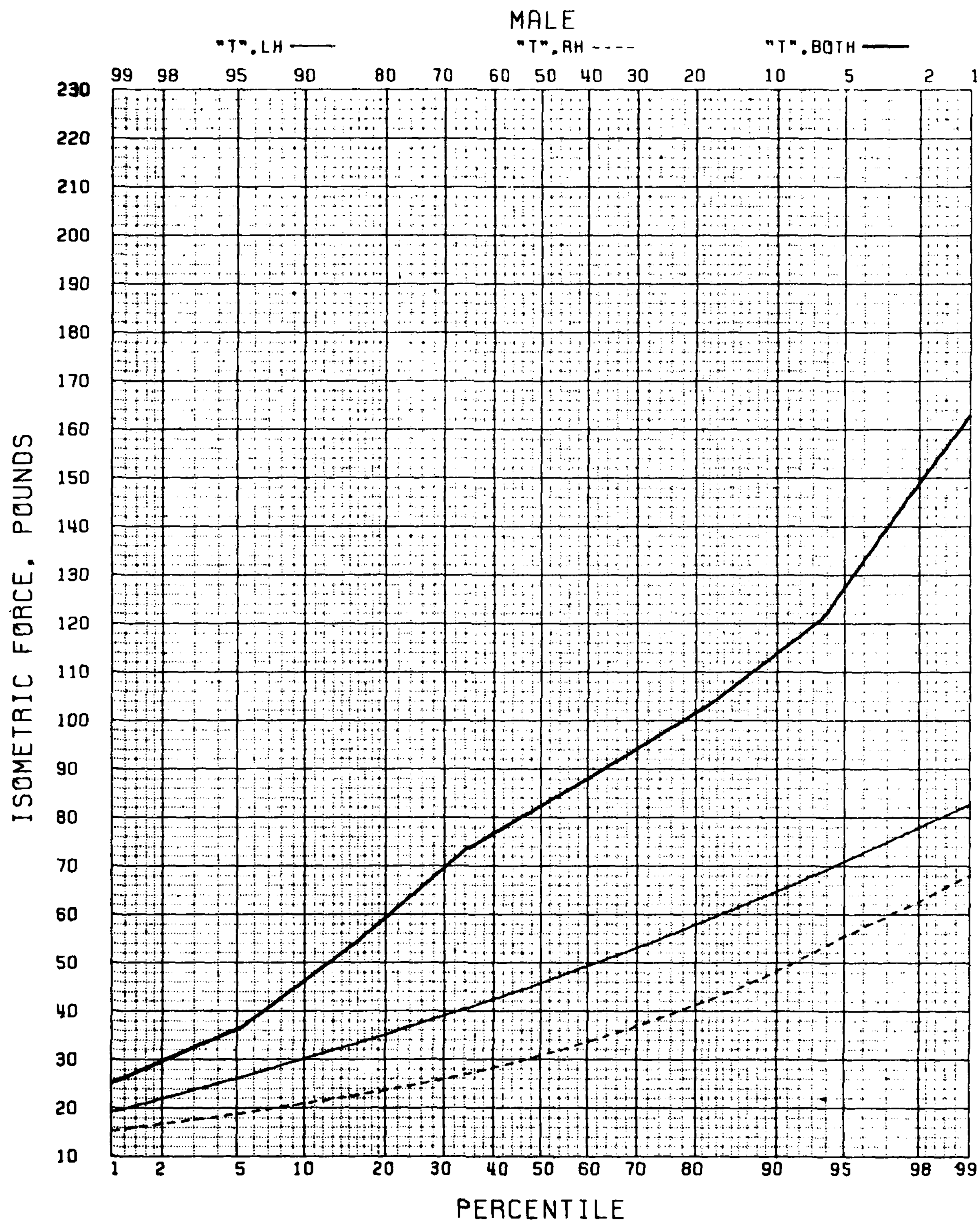

Figure 20. Distribution of Male Isometric Forces on "T" Handle, BA-22 Parachute.

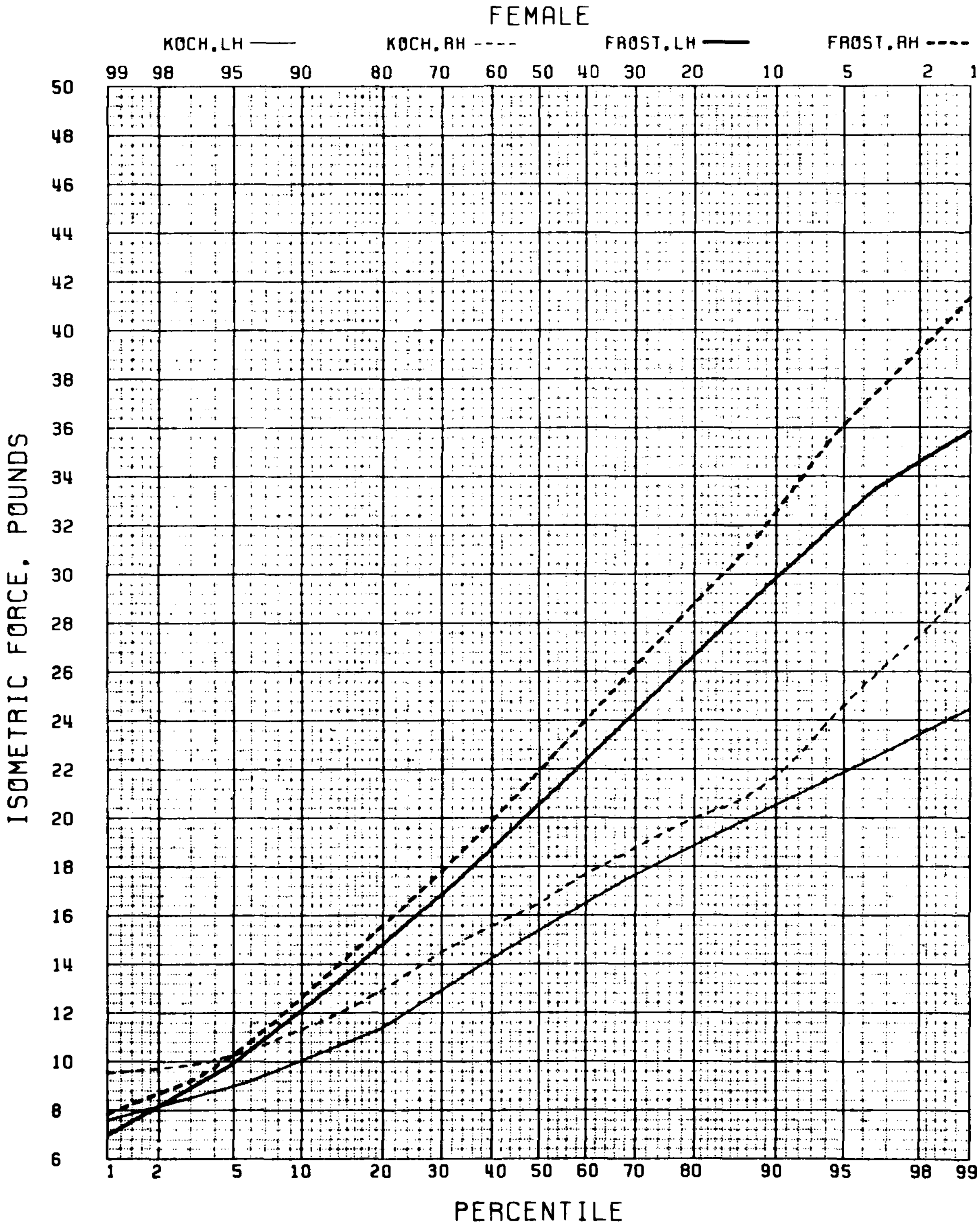

Figure 21. Distribution of Female Isometric Forces on Koch and Frost Riser Releases.

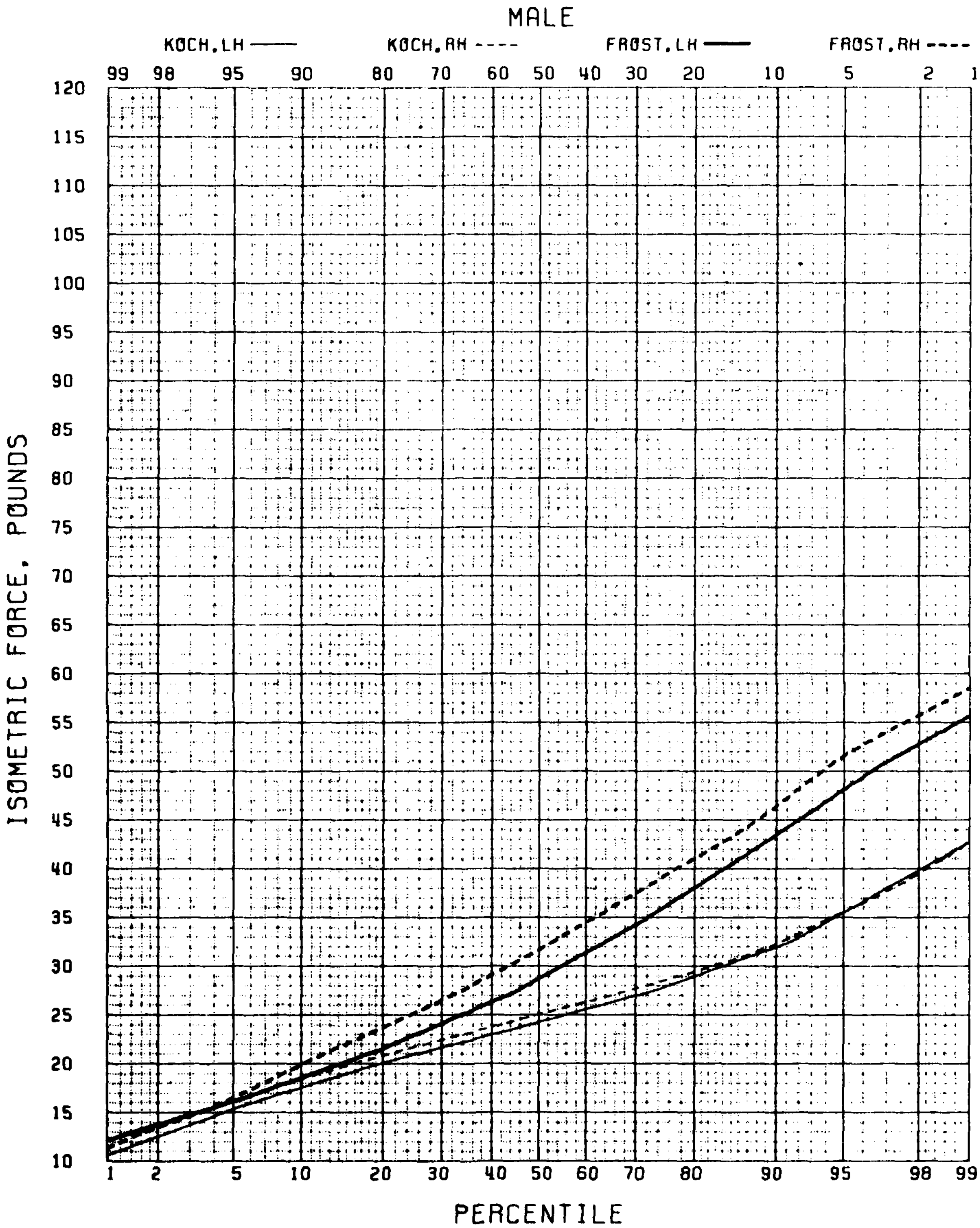

Figure 22. Distribution of Male Isometric Forces on Koch and Frost Riser Releases.

Force - to - Force Correlations. Coefficients of correlation (r) were computed for the sustained isometric forces, comparing the 16 experimental conditions against one another. A large number of correlations were fairly low, with the lowest r-value at 0.115. On the average, the correlations for males were slightly higher than those for females, and somewhat higher for the combined sample than for the males. For example, using data from both-hand pulls:

	Female	Male	Both
"L" handle vs. blast handle :	0.591	0.661	0.781
"L" handle vs. "T" handle :	0.718	0.751	0.849
Blast handle vs. "T" handle :	0.845	0.864	0.910

No highly distinct patterns could be discerned in the correlations. Exertions on ripcords had fairly low correlations to exertions on the riser releases, the highest correlation reaching 0.618. Within the riser releases, the correlations were between 0.364 and 0.822. Both-handed exertions on the various ripcords tended to have higher correlations than did other combinations. This suggests that testing prospective parachute users with a two-handed pull on one kind of ripcord handle could give a fairly good indication of their potential performance on other types of handles.

Force - to - Anthropometric Measure Correlations. Coefficients of correlation were computed for the sustained isometric forces and the 12 anthropometric measures, for females and males separately, and for both sexes combined. The computed correlations were rather low, as might be expected from numerous previous studies. The highest correlations for the males were:

biceps circumference vs. chestpack side pull: 0.523
vs. chestpack up, R : 0.527
vs. blast handle, R : 0.500

forearm circumference	vs.chestpack up, L :	0.540
	vs. chestpack up, R :	0.514
	vs. blast handle, R :	0.520
	vs. Koch, L :	0.504
	vs. Koch, R :	0.527

For females, the highest correlations were:

forearm circumference	vs. chestpack side :	0.400
wrist circumference	vs. chestpack side :	0.485
	vs. "L" handle, R :	0.420

Out of the 384 coefficients of correlation (12 anthropometric measures vs. 16 force conditions, replicated for females and males), 295 correlations (76.8 %) were not significantly different from zero with an absolute value of less than 0.250. Thus, as expected, anthropometric measures were found to be poor predictors of strength capabilities, although people with larger muscles and shorter arm segments have a tendency to produce greater forces.

Anthropometry. Results of the anthropometric measurements are given in Table 11, listing the means, standard deviations, and six cumulative percentile values for the 12 measured variables. For comparative purposes, the weight and stature data from the 1967 Anthropometric Survey of Rated Officers, and the 1968 Survey of Air Force Women are also shown in Table 11. The subject males were generally very similar to the '67 male pilots in stature, being only slightly shorter at the short end of the distribution. The female subjects, however, were taller than the '68 Air Force women, because most were selected against the 64 inch minimum stature requirement for entry into flight training. Compared to the projected female pilots, the shortest test subjects were shorter and the tallest subjects were taller. With regard to weight it can be seen that male subjects up to the 90th percentile were lighter than the '67 male pilots; only at the highest percentiles were they found to be heavier. Compared to

the '68 Air Force women and the '68 female pilots, the test subjects were generally heavier except at the very light end of the distribution where they were lighter than the female pilots. Definitions of the anthropometric variables and methods of accomplishing the measurements can be found in Appendix 2, as well in Clauser (1972) and in Grunhofer (1975).

DISCUSSIONS

Some worthwhile insights can be gained by comparing results of this study with those obtained in similar studies previously undertaken. The Sport Parachutists used 226 male and 83 female subjects, all participants of the Nationals and believed to be active parachutists. The males were between 17 and 54 years old, and the females between 19 and 44 years old. Their equipment consisted of an instrumented parachute harness without a canopy pack. The harness had leg straps and shoulder straps, with the ripcord guide going over the left shoulder acting on a mechanical force gage mounted on the back. The gage dial had one pointer for the instantaneous force, and one which maintained the maximum force achieved during an exertion. Only the maximum force was recorded. During the exertion the ripcord handle was at approximately elbow height of the subject.

The subjects wore casual summertime clothing - no heavy outer garments. The ripcord handle was gripped by inserting the thumb through the loop and wrapping the four fingers around, for all three types of pulls - left, right, and both hand. The order of using the hands is not known, but, with a total of only three exertions, fatigue is not believed to have been an influence.

The means, standard deviations and ranges of the sport parachutists data are given in Table 9. Comparing the means to those in Table 2, particularly with "L" and "T" handles, it will be noted that the sport parachutists are slightly stronger. The female sport parachutists recorded slightly higher minimum and maximum forces, indicating that this undoubtedly is a select group. The male minimum forces were similar for both groups, while the maximum forces for the sport parachutists were slightly higher. Left hand exertions by sport parachutists produced forces greater than right-handed exertions and both-hand pulls produced forces that exceeded the sum of forces of single-hand pulls. These results, again, conformed to the patterns noted in

this study. In summary, except for recording slightly higher forces, strength testing of the sport parachutists produced results quite comparable to those obtained in this study.

Other Studies. One of the earliest known investigators (Martin, 1945) made use of the S-1 seat-pack parachute on which the ripcord is located near the wearer's hip and is pulled in a forward direction. This position and direction-of-pull is sufficiently different from those used in this study as to make useful comparisons difficult if not impossible.

Reid (1973) and Pheeny (1982) used few subjects in their investigations. Reid used 11 Air Force and 11 Navy parachutists, all males, who pulled instrumented dummy ripcords during actual parachute jumps. Pheeny used 16 female Navy personnel, six of them aircrew members. Although some comparisons can be made, meaningful distribution percentiles cannot be computed from such small samples. Pheeny suspended the subjects from attachment points at the left side of their bodies, almost horizontally, to simulate a free-fall posture. Unless the suspension forces are distributed very carefully, such a position could cause the subjects to generate internal muscular tensions which have the potential of seriously affecting the forces that can be applied to the ripcords. Two different parachutes were used in the Pheeny study but the report makes no mention of the causes or significance of the differing results. The Pheeny report states that the Navy teaches a single hand pull, but recommends that it institute a two-hand pull.

Bullock (1978) used 37 subjects which matched the body size distributions of the 62 registered sport parachutists in Australia. Eight of the subjects were actual parachutists. The remaining 29 were selected from a local university. Stature, weight, age and body build distributions of the subject population closely approximated the distributions of the actual female sport parachutists.

Six different handle locations were used in Bullock's study simulating both the main parachute and the reserve parachute configurations. All tests were carried out using the right hand only. Bullock computed the distribution percentiles for the recorded isometric forces on the six handles, and conducted exhaustive analyses of force repeatability, behavior of the maximum instantaneous forces, and several other aspects of the experimental data. Based on the findings of Bullock (1978), the Federal Aviation Agency has mandated that the allowable pull force on ripcords - note that this pertains to sport parachutes only - must be reduced from 22 pounds to 15 pounds (Aviation Standard AS 8015) for any location of the ripcord handle.

For purposes of comparing our results with those of other investigators, our "T" handle data were selected because of the similarity in location and the shape of the handle to that of the handles used in the other studies. The means and ranges of all available data are given in Table 8. Not all authors investigated or reported the variables in the same manner as was done in this study, making some comparisons difficult.

Of the females, with only a few exceptions, the sport parachutists had the highest scores. One of the potentially meaningful points which is also available in our study as well as in Bullock's and the Sport Parachutists studies is the 5th percentile of female right hand exertions. The results are: sport parachutists: 17.6 lbs.; Bullock: 10.6 lbs.; and our study, "T" handle: 9.7 lbs. Here, again, the same trend that was noted for average performance is continued in that the sport parachutists recorded the largest forces. It is somewhat surprising to see that the force recorded by Bullock (1978) is only slightly higher than ours. This may have been caused by using non-parachuting subjects while duplicating anthropometric distributions, with the result that the general population has been sampled and this may not be necessarily representative of the parachuting population.

Among the males, the sport parachutists in most cases had a slight edge over the subjects in this study. The Air Force parachutists, who were tested during live jumps (as were the Navy parachutists), using both hands only, registered the highest mean and minimum performances. These values are about what one would expect from these populations, at least in proportion to one another. What does strike one are the unusually high strengths of the Navy parachutists, particularly considering that they were achieved using only one hand. An illustration in Reid's report suggests an explanation: a separate, instrumented ripcord was attached to the left riser at approximately armpit height and the subject held the ripcord so that it is almost horizontal, with his hand four to five inches from the chest. In such a position and direction, rather high forces could be generated, but it is questionable whether the ripcord could be effectively pulled in such a manner, as the instrumented ripcord is nearly perpendicular to the riser.

In summary, where experimental conditions were similar the results of this study are generally comparable to those obtained in previous studies. That subjects in the other studies produced higher minimum as well as average forces, can probably be attributed to the fact that they represent select groups, rather than the general population.

CONCLUSIONS AND RECOMMENDATIONS

The following major conclusions are drawn as a result of this study:

1. The sustained isometric force is the only one that subjects can be counted on to produce consistently, reliably, and repeatably; an initial impact loading force spike is produced only occasionally.

2. The sustained isometric force produced by males on ripcords is, on the average, approximately 1.8 times greater than that produced by females.

3. On some ripcord handles, the left hand produced higher forces than the right hand, and both-hand exertions were slightly greater than the sum of individual hand exertions.

4. Almost all males are capable of exceeding the 27-pound force limit when using both hands. With regard to the total population, the number of subjects capable of pulling 27 lbs. decreases when exertions are made by females or when only one hand is used to produce the exertion.

5. Because the force-to-force correlations for two-handed exertions were high, testing potential parachute users with a two-handed pull could serve as a reasonable indication of their ability to apply a force to a ripcord.

6. Comparing the results of our study with previous studies disclosed that our data are generally comparable, and that aircrew members can be expected to be stronger than the weakest participants in our study. Our subjects are representative of the general population.

7. Subjects were able to exert a larger force on the Frost riser

release than on the Koch type.

Accordingly, the following recommendations can be made:

1. The two-handed pull, as currently taught in Air Force survival training, should be continued, as it takes advantage of the maximally available forces developed while using both hands.

2. According to the observed strength data, the maximum allowable force of 27 lbs. to activate a ripcord should not be increased, but consideration should be given to lowering it to accommodate females.

3. The strength of parachute users could be tested by requesting them to make an exertion on an appropriately instrumented ripcord which would identify those who are not capable of producing the required forces.

Table 1. Time of Occurrence of Maximum Forces.

Interval:	1st	2nd	3rd	4th second
Males	15.9%	20.5%	22.0%	41.4%
Females	20.6%	17.9%	19.2%	42.3%

Table 2. Summary Statistics for Sustained Isometric Forces (Pounds) on Parachute Ripcords.

Handle	Hand	Female				Male			
		Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
Side	R	17.9	5.4	8.0	33.3	33.3	11.0	12.9	81.9
Upward	L	16.2	5.7	6.0	34.1	29.6	10.2	12.5	61.9
	R	16.9	5.1	6.0	33.8	30.8	11.4	11.8	66.6
"L"	L	21.8	5.8	10.6	60.8	36.2	16.6	19.0	181.3
	R	22.3	5.9	11.1	38.6	37.2	11.2	21.6	83.4
	B	39.8	10.9	21.6	78.4	75.6	23.8	36.3	205.9
Blast	L	23.1	7.4	10.2	46.3	41.0	10.3	21.8	83.3
	R	19.1	4.2	8.7	29.9	35.3	8.0	19.3	56.1
	B	48.0	18.0	19.3	104.3	83.8	30.0	32.0	177.5
"T"	L	25.5	8.7	7.6	57.6	46.5	13.3	18.3	85.0
	R	17.4	5.0	7.3	30.9	32.8	11.1	14.8	70.3
	B	45.4	16.6	16.6	98.2	81.8	27.6	26.8	178.6

Table 3. Summary Statistics for Sustained Isometric Forces (Pounds) on Riser Releases.

Handle	Hand	Female				Male			
		Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
Koch	L	15.2	4.1	6.0	26.6	24.5	6.0	8.2	45.9
	R	16.7	4.3	8.0	31.1	25.3	5.8	12.3	48.6
Frost	L	20.8	6.9	7.0	37.4	29.7	9.7	12.0	55.0
	R	22.3	7.7	8.0	40.7	32.4	10.4	10.0	57.2

Table 4. Significant Effects from Analysis of Variance of Parachute Ripcord Data: Sex x Handle x Hand.

Effect	d.f.	F
Sex	1, 208	247.5
Handle	3, 624	89.7
Hand	1, 208	96.4
Handle x Sex	3, 624	9.3
Handle x Hand	3, 624	129.4

Table 5. Comparison of Single and Both Hand Performance (Pounds).

Sex	Handle	Left	Right	Sum	Both
	"L"	21.8	22.3	44.1	39.8
F	Blast	23.1	19.1	42.2	48.0
	"T"	25.5	17.4	42.9	45.4
	"L"	36.2	37.2	73.4	75.6
M	Blast	41.0	35.3	76.3	83.8
	"T"	46.5	32.8	79.3	81.8

Table 6. Significant Effects from Analysis of Variance of Riser Release Data: Release x Hand x Sex.

Effect	d.f.	F
Release	1, 209	141.0
Hand	1, 209	52.9
Sex	1, 209	132.4

Table 7. Percentages of Subjects who Could not Exceed 27 Pound Pull on Ripcords.

Handle	Hand	Female	Male
Side	R	93	33
Upward	L	96	45
	R	97	45
"L"	L	89	25
	R	84	20
	B	10	0
Blast	L	78	7
	R	96	17
	B	11	0
"T"	L	64	6
	R	97	39
	B	10	2

Table 8. Results of Ripcord Pull Tests on BA-18 Parachutes.

Force, lbs.	N	Percent	Cum. Percent
16	1	2.2	2.2
17	5	11.1	13.3
18	13	28.9	42.2
19	8	17.8	60.0
20	7	15.6	75.6
21	6	13.3	88.9
22	3	6.7	95.6
23.5	1	2.2	97.8
24	1	2.2	100.0

Average=19.26 Total=45

Table 9. Sport Parachutists' Data (Pounds):
Means, Standard Deviations, and Ranges.

Hand	Mean	Std. Dev.	Min.	Max.
FEMALE				
Left	35.6	10.6	18.0	72.0
Right	27.5	8.5	16.0	71.0
Both	73.9	19.8	34.0	150.0
MALE				
Left	51.0	13.8	14.0	100.0
Right	40.0	11.2	17.0	88.0
Both	107.8	26.9	44.0	220.0

Table 10. Comparison of Performance among Several Other Studies.

	Left			Right			Both		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
FEMALE									
"T"	25.5	7.6	57.6	17.4	7.3	30.9	45.4	16.6	98.2
S.P.	35.6	18.0	72.0	27.5	16.0	71.0	73.9	34.0	150.0
B.	-	-	-	16.3	-	-	-	-	-
NB-7	35.4	16.0	53.0	37.1	20.0	64.0	56.0	29.0	107.0
NB-8	27.8	17.0	38.0	27.1	15.0	64.0	55.7	37.0	81.0
MALE									
"T"	46.5	18.3	85.0	32.8	14.8	70.3	81.8	26.8	178.6
S.P.	51.0	14.0	100.0	40.0	17.0	88.0	107.8	44.0	220.0
AF	-	-	-	-	-	-	114.0	59.0	175.0
Navy	-	-	-	117.0	40.0	210.0	-	-	-

Note:

"T" = "T" handle, our study; M = 104, F = 107

S.P. = Sport Parachutists; M = 226, F = 83

B. = Bullock study; F = 37

NB-7 = Pheeny study, using NB-7 parachute; F = 16

NB-8 = Pheeny study, using NB-8 parachute; F = 16

AF = Reid study, using Air Force subjects; M = 11

Navy = Reid study, using Navy subjects; M = 11

Table 11. Means, Standard Deviations and Distribution Percentiles of Anthropometric Dimensions. *

	Mean	S.D.	1%	5%	10%	90%	95%	99%
FEMALE								
Weight	140.7	23.4	97.5	108.4	114.8	171.2	186.2	212.7
Span	167.7	7.08	152.5	156.4	158.2	176.6	179.2	182.8
Stature	166.8	5.39	156.6	158.3	160.0	174.4	176.1	179.3
Chest Circ.,Scye	87.7	6.19	78.0	79.3	81.1	94.7	101.6	106.3
Biceps Circ,Flxd	28.2	3.08	22.4	23.8	24.7	31.6	33.8	37.2
Forearm C, Flxd	25.5	1.86	21.8	22.6	23.5	28.2	28.5	31.3
Wrist Circ.	15.2	0.82	13.7	13.9	14.2	16.2	16.6	16.9
Acromion-Radiale	31.1	1.48	27.4	28.5	29.1	32.9	33.6	33.9
Radiale-Stylion	24.9	1.36	22.4	22.8	23.3	27.1	27.4	27.7
Hand Length	18.0	0.95	15.8	16.4	16.8	19.2	19.6	20.2
Biacromial Brdth	37.4	1.60	33.4	34.3	35.2	39.1	39.8	41.3
Sitting Height	87.4	3.16	71.2	83.4	84.3	91.2	92.5	93.4

For comparison, Weight and Stature of USAF Women (1968 Survey):

Weight	127.3	16.59	96.4	102.3	106.9	148.5	156.4	175.2
Stature	162.1	6.00	149.5	152.4	154.3	169.9	172.2	176.5

For comparison, Weight and Stature of USAF Female Pilots (a subsample selected to meet body size requirements for flight training):

Weight	129.5	10.44	107.5	111.8	115.3	142.9	146.5	154.0
Stature	167.4	4.06	161.4	161.8	162.3	173.0	174.9	178.9

* Note: weight is in pounds. All other dimensions are in centimeters. For definitions of the Anthropometric Dimensions, see Appendix 2.

Table 11 - continued. *

	Mean	S.D.	1%	5%	10%	90%	95%	99%
MALE								
Weight	166.9	25.1	100.7	131.2	134.9	196.1	214.6	234.4
Span	180.8	8.59	158.2	166.7	169.0	192.5	193.0	199.1
Stature	176.9	6.70	160.0	164.9	167.9	185.4	187.8	190.7
Chest Circ.,Scye	99.9	6.82	82.4	89.0	91.1	107.6	110.2	119.5
Biceps Circ. Flxd	32.8	2.87	32.2	28.2	29.8	36.6	37.8	39.1
Forearm C, Flxd	29.4	1.98	22.7	25.9	27.0	31.9	32.4	33.7
Wrist Circumf.	17.0	1.17	13.2	14.9	15.7	18.5	19.0	19.7
Acromion-Radiale	33.0	1.84	28.1	29.9	30.5	35.1	36.0	36.7
Radiale-Stylion	27.2	1.61	23.3	24.7	25.3	29.3	29.7	30.7
Hand Length	19.3	0.91	17.0	17.8	18.0	20.4	20.9	21.2
Biacromial Brdth	41.6	2.26	32.3	38.1	39.0	44.0	45.2	46.5
Sitting Height	93.0	3.89	83.3	85.5	87.9	97.6	98.3	99.1

For comparison, Weight and Stature of USAF Pilots (1967 Survey):

Weight	173.5	21.42	127.6	140.2	146.8	201.7	210.7	227.7
Stature	177.3	6.19	163.2	167.2	169.4	185.4	187.7	191.8

* Note: weight is in pounds. All other dimensions are in centimeters. For definitions of the Anthropometric Dimensions, see Appendix 2.

APPENDIX 1

GENERAL INSTRUCTIONS

Parachutes have been built for many years. Recently, however, it has turned out that there is only vague knowledge of what kind of forces parachute users are capable of applying to various activation handles. Obviously, if it takes more force to activate something than what the user can produce, the results can only be disastrous. The current study is done to remedy this situation.

During the experiment you will be asked to put on a parachute. This will be done with you standing on the ground in a laboratory - there is no flying or jumping involved. Then you will be asked to make 16 maximum voluntary exertions (hard pulls) on various parachute activators. Each exertion is to last 5 seconds - you will start on a signal from the experimenter, and continue to pull until the end of 5 seconds is signalled by a buzzer. There is a required 2 minute rest period before you may use the same hand again, as otherwise you lose strength from overexertion.

So that people's ability to apply forces can be predicted with some accuracy, we also will take some measurments of your body: its heights, lengths, and distances around your body and its segments will be measured. An anthropometer, tape, and calipers are used. To facilitate measuring, a number of small water soluble marks will be made on your body with a red or blue pencil. This test has been designated by the Human Use Review Committee as having no risk to you.

You should not expect any benefits from the participation in this study.

APPENDIX 2

DEFINITIONS OF THE ANTHROPOMETRIC DIMENSIONS

Weight: Subject is wearing underwear. A balance type scale is read to the nearest pound.

Span: Subject stands erect, head facing forward, heels together and back against a rear wall. Arms and fingers are extended horizontally to their maximum, the longest finger of one hand just touching a side wall. Using a block just touching the longest finger of the other hand, measure on a rear-wall mounted scale the distance from the side wall to the block.

Stature: Subject stands erect with the head in the Frankfort plane. With the anthropometer arm firmly touching the scalp, measure the vertical distance from the standing surface to the top of the head.

Chest circumference at scye: Subject stands erect, arms initially raised, then lowered after the tape is in place. Holding a tape in a horizontal plane at the level of the scye, measure the maximum circumference of the chest during normal breathing.

Biceps circumference, flexed: Subject holds the right upper arm horizontally, the lower arm vertically upward, and makes a tight fist. Using a tape, measure the circumference of the arm at the level of the greatest superior protrusion of the tensed biceps.

Forearm circumference, flexed: Subject holds the right upper arm horizontally, the lower arm vertically upward, and makes a tight fist. Using a tape, measure the circumference of the arm at the level of maximal protrusion of the brachio-radialis muscle.

Wrist circumference: Subject stands, with the right elbow extended, and with the hand about 30 cm from the side of the body. Holding a tape perpendicular to the long axis of the lower arm, measure the minimum circumference of the wrist proximal to the radial and ulnar styloid processes.

Acromion - radiale length: subject stands erect with the arms hanging at sides. Using a beam caliper, measure the straight-line distance between the right acromion and right radiale.

Radiale - stylion length: Subject stands erect with the arms hanging at sides and the right forearm supinated. Using a beam caliper, measure the straight-line distance between the right radiale and right stylion.

Hand length: Subject stands with the right elbow flexed, palm up, fingers extended and together. With the bar of a sliding caliper parallel to the long axis of the hand, measure the distance between the distal wrist crease and the tip of the longest finger.

Biacromial breadth: Subject sits erect, head in the Frankfort plane, arms hanging relaxed, forearms and hands extended forward horizontally. Using a beam caliper, measure the horizontal distance between the right and left acromion landmarks.

Sitting height: Subject sits erect, head in the Frankfort plane, upper arms hanging relaxed, and forearms and hands extended forward horizontally. With the anthropometer arm firmly touching the scalp, measure the vertical distance from the sitting surface to the top of the head.

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